TECHNICAL HIGHLIGHTS

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FINAL TECHNICAL REPORT

ONR CONTRACT NO. N00014-67-C-0218

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Washington, D. C.

Final Technical Report
Covering Research on High Performance
Composites being conducted for the
ADVANCED RESEARCH PROJECTS AGENCY
Under ONR Contract No. N00014-67-C-0218
Formerly No. N00014-66-C-0045

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TECHNICAL HIGHLIGHTS

Introduction

The Monsanto Company/Washington University Association was formed under Office of Naval Research/Advanced Research Projects Agency sponsorship in 1965 with concurrent, interdependent objectives. These were:

(a) to establish a broader technical base for the area of composite materials through fundamental research and an active communications effort,

(b) to develop an interdisciplinary teaching program to train scientists and engineers in efficient utilization and design with composites and

(c) to demonstrate a means by which an effective working relationship can be formed between a university and private industry.

Since the goals were all somewhat exploratory in nature, maximum flexibility was permitted in choosing and modifying the approaches to be followed, in staffing, and in reporting. Furthermore, initial funding and the first contract renewal were for two-year periods to

facilitate planning and to allow time for the impact of the program to be measured. In general, all the goals were satisfactorily met. In the following paragraphs the major accomplishments made under the contract are briefly summarized. More detailed lists of reports and publications, patents, and degree recipients are appended in later sections.

Major Technology Advances

As measured by their acceptance and use in the technological community, the Association contributed major technical advances in three general areas: Chemistry and Physics, Mechanical Analysis and Characterization, and Fabrication and Processing.

The chemistry of silane coupling agents was unraveled enabling improvement of a wide range of coupling agents. Industrial producers of coupling agents are now making use of the work to develop new types of coupling agents. A new flexible innerlayer and a process for applying it to continuous, large diameter glass filament were developed. It is highly likely that this technology will be applied directly to the manufacture of glass reinforced pipelines. The innerlayer greatly improves fatigue resistance and elevates the strength properties of the large diameter glass system to those of small diameter glass, making a superior, economical pipeline system available.

In the area of mechanical analysis and characterization, many of the structure-property relations currently used in designing composite structures were developed under the ONR/ARPA contract. The stiffness design equations currently employed in the Air Force Design Manual were developed at Washington University. A tensor failure criteria

for continuous fiber laminates, as well as fracture toughness measuring procedures, were developed under the contract and are currently in use by the technological community.

With regard to fabrication and processing, basic rheological parameters important in the transfer and injection molding of filled melts were identified and characterized. These concepts are currently in use within the Monsanto Company as well as in other corporations. New ways to produce short-fiber molding compounds for both thermosetting and thermoplastic matrices were developed and patented.

In order to disseminate the technology and data generated under the contract, 170 research reports were written over the contract period. Over 85 publications in reputable journals resulted. Seven patents have so far been issued on technology developed under the contract. Detailed lists of patents, publications, and reports are appended in later sections of this report.

Examples of Technical Exchange and Interaction with the Materials Community

One of the measures of success in accomplishing the above objectives is the degree of technical exchange and interaction with the materials community. Under the ONR/ARPA contract, this interaction took the form of people-to-people contact first via collaboration with industrial and government organizations.

In 1971, the Monsanto/Washington University Association participated in a structural design project involving the McDonnell-Douglas F-15 aircraft. Part of the aircraft's wing, the spar root fitting for the

intermediate torque box, was selected as the component for design and five design concepts were developed utilizing high performance fibers with both plastic and metal matrices.

The Association also participated in an evaluation of a fractured experimental speed brake with members of Goodyear Aerospace Corporation, at their request. The component was fabricated for the F-5 plane by Goodyear under Air Force Contract. Results from the study defined 1) the contribution of the continuous fibers to the structure and the extent to which maintaining the position of these fibers during molding is a problem, 2) the extent to which fiber position and orientation changes when molding chopped prepreg using matched metal dies, and 3) the source and cause of the fracture.

Consultations were held with the Polymers Division of the National Bureau of Standards concerning possible directions that composites research might take at NBS.

Samples of very highly aligned dispersed graphite fibers in an epoxy matrix were obtained for evaluation from two sources in the United Kingdom, the Explosives Research and Development Establishment and Fothergill and Harvey. These highly aligned systems were characterized both mechanically and morphologically.

Concepts and technology developed under the Contract are now being used by the Rubber Chemicals Division of Monsanto Industrial Chemicals Company in Akron to develop new reinforced rubber systems containing unregenerated cellulose short fibers as reinforcement. Some of these systems are nearly ready for marketing.

Several small testing contracts have been completed by Washington University using specialized equipment developed under the contract especially for anisotropic materials. Among these participating industrial concerns are Arundale Manufacturing, Inc., Rawlings Sporting Goods Company, Western Textile Products, and Tiffany Industries, Inc.

Consultations have recently been held with Owens-Corning Corporation, Air Products Company, and Lord Corporation concerning ways in which these companies might productively interact with the Washington University research program.

A second form of interaction with the materials community involved efforts by the Association to stimulate education of the materials community in the area of composite materials and to serve as a vehicle for gathering and desseminating the work of others in the field.

Early in the Contract (1967), the Monsanto/Washington University Association sponsored a Composite Materials Workshop on the Physical Aspects of Composite Materials. The proceedings of this workshop were published by Technomic Publishing Company as Volume I of their Progress in Materials Science Series.

The authoritative Journal of Composite Materials was initiated by the Association in 1967. It is published quarterly by Technomic Publishing Company and continues to be the leading journal in the area of the physics and mechanics of composite materials.

The Monsanto/Washington University Association organized six symposia on advanced composites during the duration of the Contract. These meetings were held annually, and attracted national and

internation attention. The proceedings of the last of these, "Composite Materials in Engineering Design", were published by the American Society for Metals in 1973 (one volume 727 pages).

For the last several years, Washington University has organized and conducted a short course entitled, "Advances in Reinforced Plastics Technology". This 3-day intensive course is sponsored by the Plastics Institute of America and draws heavily on members of the Association for lecturers.

University/Industry Coupling An Evaluation

A number of requirements and possible barriers to an effectively coupled effort have become apparent in the course of the Program. The requirements include in order of importance:

1. Geographic proximity so that day-to-day interaction is possible (and convenient).
2. Mutual dedication to the goals (with clear cut benefits to each of the partners) and mutual dependence on one another to provide key expertise and/or facilities (thus forcing interaction where otherwise there might be hesistance).
3. Flexibility in administrative procedures, use of equipment and facilities, experimental approaches and reporting on the part of both organizations.
4. A single program manager, but interaction between counterparts at all administratives and technical levels.
5. Willingness of the industrial partner to become involved in work sufficiently fundamental to meet academic degree standards,

and willingness of the academic partner to maintain a practical focus to the work and facilitate use of, but protect (patents, etc.), results of possible commercial value.

6. Freedom to publish and broad interactions within the technical community. These require that the problems be recognized as important and long range enough for thesis research, yet not so intensely competitive as to hamper meaningful technical exchange with others in the field outside the parent organizations.

As implied by the various requirements listed, among the more important barriers to an effective coupling program are:

1. Wide geographic separation.
2. Insistence on such rigid procedures and protocol that communication is reduced.
3. Demand for poorly defined organization or existence of complete autonomy or independence by either partner.
4. A highly competitive atmosphere preventing publication or technical exchange outside the program.
5. Unwillingness to accept some practical focus and/or insistence on complete use orientation.
6. Inability of either partner to make allowances for and adjust to the pace of the other (that of the university will necessarily be slower).

Tendencies for some of these occasionally cropped up in the Monsanto/Washington University program from time-to-time; fortunately, these were largely overcome.

The success of the coupling demonstration is exemplified by the fact that the two organizations have continued to work together in bidding for additional contracts, by appointment of some of the faculty members as Monsanto consultants and some of the Monsanto staff as affiliate faculty, and by voluntary cost-sharing by Monsanto of a portion of the coupled program having possible commercial implications.

Educational Program

The Materials Science and Engineering Program of Washington University School of Engineering and Applied Science is a flexible, interdisciplinary activity designed to encourage graduate study and research in the area of homogeneous and multi-phase structural materials with heavy emphasis on reinforced plastics. It was developed largely over the last eight years under the auspices of the ONR/ARPA contract. The Program stresses the integration of basic and applied research on reinforced plastic systems and provides for the education of materials scientists and engineers in this field.

The Program is now well established and enjoys international recognition as one of the few in the United States dealing with the preparation and long-term performance evaluation of polymeric composites. Since 1967, 22 master's degrees and 28 doctoral degrees have been awarded; 8 graduate students and one post-doctoral fellow are currently in residence. Faculty in the Program hold their appointments from the Departments of Chemical Engineering and Mechanical Engineering. Affiliate faculty participate from Monsanto Company and the Air Force Materials Laboratory. A list of current faculty in the Program is

appended. Most graduates of the Program are now employed by industry and are highly sought after by materials-oriented companies. A list of graduates and their current employers is included in a later section.

Preparation of a Monograph on Short Fiber Composites

From a technical point of view, the unique feature of this contract was its emphasis on short fiber composites as structural materials. We undertook the writing of a monograph to define the role of short fiber systems in structural materials, to outline the state-of-the-art in short fiber technology development, and to summarize the Monsanto/Washington University Association's contributions to this fast-growing area of Materials Science and Engineering.

Unfortunately, writing of the monograph did not start until near the end of the Contract. As Association members went on to different things after the Contract concluded, it became more difficult to meet target milestones for completion of the book. Completion is now set for Fall, 1975. Editing, rewriting and drawing are now proceeding. A chapter-by-chapter status report appears below.

Title: Engineering Composites Reinforced With Short Fibers

Publisher: Marcel Dekker, New York

Preface: 1st draft completed

Chapter 1 - Introduction - 1st draft completed

Chapter 2 - Constituent Materials - 1st draft completed

Chapter 3 - Prediction of Composite Performance - 1st draft completed

Chapter 4 - Practical Performance Levels - 1st draft not complete, resource references and data complete

Chapter 5 - Laboratory Processing of Composites - 1st draft completed

Chapter 6 - Commercial Processing of Short Fiber Composites - 1st draft completed

Chapter 7 - Composite Characterization Techniques - 1st draft completed

Chapter 8 - Composite Testing - 1st draft not completed (all subsections completed but not drawn together)

Chapter 9 - Design with Composite Materials - 1st draft completed, 2nd draft completed

Appendices

Data Analysis and Reduction - 1st draft completed

Bibliography - not completed

Glossary and Index - not completed

PATENTS

To date the following patents based on Contract-sponsored research have been issued.

U.S. 3,518,221 - Shaped Composites Comprised of Filler Particles Enveloped in a Thermosetting Resin - A. S. Kenyon and R. J. Slocombe.

U.S. 3,562,198 - Epoxide Resin Solution - R. J. Slocombe.

U.S. 3,580,882 - Mica Reinforced Composites - L. E. Nielsen and J. E. Fields.

U.S. 3,598,693 - Molding Composition and Method - H. M. Anderson and J. E. Calfee.

U.S. 3,626,041 - Apparatus and Process for Making Continuous Filament - J. E. Fields and E. H. Mottus.

U.S. 3,708,456 - Polycondensate Reinforcement Process Using an Interfacial-Forming Technique - J. L. Kardos.

U.S. 3,790,438 - Ribbon Reinforced Composites - L. E. Nielsen and T. B. Lewis.

PUBLICATIONS FROM MONSANTO/WASHINGTON UNIVERSITY ASSOCIATION

Internal HPC No.	Authors	Title - AD No.	Publication Information
65-1	C. Templeton	Fabrication Techniques for Composite Materials, Monsanto Lit. Survey 1673 AD 488380	
65-2	D. F. Siegmund	Crack Theory and Stress Analysis of Composite Systems Monsanto Lit. Survey 1674 AD 488381	
65-3	* W. J. Calvin	Rheology of Filled Systems Monsanto Lit. Survey 1675 AD 488382	
65-4	* W. J. Calvin	Surface Energy Monsanto Lit. Survey 1676 AD 488383	
65-5	R. A. Landy	Tape and Ribbons in Composites Monsanto Lit. Survey 1677 AD 488384	
65-6	M. K. Collins	The Use and Function of Coupling Agents in Glass-Reinforced Plastics Monsanto Lit. Survey 1678 AD 488385	

* Indicates author(s) from Washington University

65-7	* V. R. Vincent	Experimental Data to Support Existing Theories on the Physical and Mechanical Properties of Composite Materials Monsanto Lit. Survey 1679 AD 488386
65-8	W. C. Peterson	Fibers for High Performance Composites Monsanto Lit. Survey 1680 AD 488387
65-9	M. J. Farrell	Surface Migration or Diffusion of Gases or Liquid Along Solid Interfaces Monsanto Lit. Survey 1681 AD 488388
66-1	C. M. Bower	Computerized Research Index AD 481654
66-2	D. C. Morris & C. H. Adams	Isotropic and Composite Materials for High Performance (Structural) Applications AD 481654
66-3	* H. J. Duffey	Evaluation of Mathematical Analyses of Discontinuous Fiber Reinforced Composites AD 481654
66-4	P. E. Chen	Stress Fields Around Edge Cracks AD 481654
66-5	A. S. Kenyon	Thick and Multiphase Zone Between Matrix and Reinforcing Agent AD 481654
66-6	J. F. Schaefer & D. J. Morotz	Diffusion of Water at a Glass-Resin Interface AD 481654

66-7	R. E. Lavengood	Characterization of Whisker Fibers AD 481654	
66-8	R. B. Weil	Solid State Physics of High Performance Fibers (internal progress report)	
66-9	R. M. Anderson	Relationships Between Matrix Properties and Dynamics Fatigue Resistance in Filament Wound Composites AD 481654	
66-10	M. K. Collins	The Rheology of Fibrous Materials in Low Viscosity Media: A Literature Survey-- Monsanto Lit. Survey 1682 AD 488389	
66-11	C. M. Bower	Glossary to the Science of Composites AD 634606	
66-12	(internal)	Composite Materials Parts I & II Washington University Course 641-642	
66-13		First Annual Project Review and Technical Report AD 487208	
66-14 (internal)	*H. J. Duffey	Evaluation of Mathematical Analysis of Discontinuous Fiber Reinforced Composites	
66-15	P. E. Chen	Stress Fields Around Parallel Edge Cracks in a Tensile Specimen AD 650340	J. Composite Materials 1, No. 1, Jan. 1967

Note: 66-1 thru 66-7 and 66-9 are in one volume--AD 481654

66-16 (internal)	R. M. Anderson	Some Major Factors Controlling Torsional Fatigue Life of Fiber Reinforced Plastic Composites	
66-17	* A. S. Kenyon & H. J. Duffey	Properties of a Particulate Filled Polymer AD 659619	Polymer Eng. Sci., 7, No. 3, July 1967
66-18	* D. A. Ludwig	Dry-Mix Molding (Thesis)	
67-19 (internal)	G. L. McVay	Unidirectional Orientation of Short Fibers in Composites	
67-20	L. E. Nielsen & P. E. Chen	Young's Modulus of Composites Filled with Randomly Oriented Fibers AD 670322	J. of Materials, 3, No. 2, June 1968
67-21 (internal)	O. deS. Deex	Thermally Stable Polymers: A Survey of Recent Works Monsanto Lit. Survey 1723	J. Composite Materials, 1, No. 2, April 1967
67-22 (See Below)			
67-23 (part of Second Annual - AD 658533)	* S. W. Tsai & P. E. Chen	Longitudinal Stiffness of Discontinuous Fiber Composites	
67-24 (internal)	M. Dub	Granular Prepreg Compositions Monsanto Lit. Survey 1727	
67-25 (internal)	W. H. Cook	Application of Electrokinetic Phenomena to the Preparation of Fiber-Reinforced Composites	
67-26 (internal)	R. T. Coyle	Chemical Strengthening of Glass Fibers	
67-22	J. D. Fairing	Examination of Fracture Surfaces by Scanning Electron Microscopy AD 657863	J. Composite Materials, 1, No. 2, April 1967

67-27 (internal)	L. Leibovich	The Influence of an Applied Electric Field on the Behavior of Particles Suspended in an Organic Fluid	
67-28		Second Annual Project Review and Technical Report, 1967 (July) AD 658533	
67-29	*	Mechanics of Composites, Engineering 772, Washington U., Lecturers notes Fall 1966	
67-30 (part of Second Annual)	J. E. Fields & L. E. Nielsen	Dynamic Mechanical Properties of Some Polymeric Acid Zinc Salts	J. Appl. Polymer Sci., Vol. 12, pp. 1041-1051 (1968)
67-31 (Part of Second Annual)	* S. W. Tsai & N. J. Pagano	Invariant Properties of Composite Materials AD 668280	Composite Materials Workshop--Progress in Materials Science Series, Vol. 1
67-32	R. M. Anderson & R. E. Lavengood	Variables Affecting Strength and Modulus of Short Fiber Composites AD 669475	SPE Journal, 24, 3 March 1968
67-33	J. R. Joseph, J. L. Kardos & L. E. Nielsen	The Growth, Morphology and Reinforcement Potential of Low Molecular Weight Crystals in Amorphous Polymeric Matrices	J. Appl. Polymer Sci., 12, 1151-1165 (1968)
67-34 (Overview paper)	T. L. Tolbert	Fabrication of Short Fiber Reinforced Composites	
67-35	A. S. Kenyon	Roles of the Interface in Glass-Epoxy Composites AD 679116	J. Colloid and Interface Science, 27, No. 4 Aug. 1968

67-36	* S. W. Tsai & R. L. Thomas	A Critical Design Comparison of Composite Stiffness	
67-37	* A. T. DiBenedetto	The Study of Fracture Mechanisms	
67-38	* A. T. DiBenedetto	Polymer-Filler Interactions in Composite Materials	
67-39	* S. W. Tsai	Environmental Factors in the Design of Composite Materials	
67-40	P. E. Chen	Binding and Buckling of Anisotropic Plates AD 664986	Composite Materials Workshop--Progress in Materials Science Series, Vol. 1
67-41 (overview paper)	* S. W. Tsai	Some Recent Mechanics Analyses of Composite Materials	
67-42	T. L. Tolbert	Reinforcement of Organic Matrices with Discontinuous High Performance Fibers	
67-43	R. G. Schierding	Measurement of Whisker Orientation in Composites by x-ray Diffraction AD 681334	J. Composite Materials, 2, No. 4, Oct. 1968
67-44	L. E. Nielsen	Relation Between Viscosity and Moduli of Filled Systems AD 667625	J. Composite Materials, 2, No. 1, Jan. 1968
67-45	H. M. Andersen & D. C. Morris	Encapsulated Short Fiber Molding Compounds	SPI Proceedings, Feb. 1968

67-46	T. L. Tolbert	High Performance Composites Reinforced with Discontinuous Fibers and Whiskers AD 670251	ASTME EM 68-128 1968
67-47	T. B. Lewis & L. E. Nielsen	Viscosity of Dispersed and Aggregated Suspensions of Spheres AD 679115	Trans. Soc. Rheology, 12:3, 421-443 (1968)
67-48	* A. Wambach, K. Trachte A. T. DiBenedetto	Fracture Properties of Glass Filled Polyphenylene Oxide Composites AD 679118	J. Composite Materials, 2, No. 3, July 1968
67-49	L. E. Nielsen	The Mechanical and Other Physical Properties of Polyelectrolyte Salts in the Solid State AD 832790	ACS Polymer Preprint 9, No. 1, 596 (April 1968)
67-50	A. S. Kenyon & L. E. Nielsen (part of Interim report--Dec. 1967)	Characterization of Network Structure of Epoxy Resins by Dynamic Mechanical and Liquid Swelling Tests AD 696029	J. Macromol. Sci.-Chem., A3(2), 275-295, March 1969
67-51 (part of 2nd Annual)	P. E. Chen	Stress Fields Around Interior Cracks AD 709545	Proceedings, 5th International Congress on Rheology, Vol. 1, Univ. of Tokyo Press & Univ. Park Press, 1969
67-52 (part of Interim report--Dec. 1967)	* O. Ishai, R. M. Anderson, R. E. Lavengood	Failure-Time Characteristics of Continuous Unidirectional Glass-Epoxy Composites in Flexure AD 709546	J. of Materials, 5, No. 1 184-208 (Mar. 1970)
67-53 (part of Interim report--Dec. 1967)	* R. E. Lavengood & O. Ishai	Defomational Characteristics of Unidirectional Glass-Epoxy Composites in Flexure	J. of Materials, 5, 3, 684-697 (1970)

67-54		Monsanto/Washington University Association Interim Report December 1968 AD 827065	
67-55	P. E. Chen	On the Stability of Parallel Edge Cracks AD 834850	
67-56	Void		
67-57	L. E. Nielsen	Crosslinking-Effect on Physical Properties of Polymers AD 834683	J. Macromol. Sci., C3(1) 69 (1969) Reviews-Macromol. Chem., Vol. 4, 69 (Feb. 1970)
68-58	J. D. Fairing	Fractography of Composite Materials AD 669476	
68-59	* O. Ishai	The Effect of Temperatures on the Delayed Yield and Failure of "Plasticized" Epoxy Resin AD 841951	Polymer Engineering & Science, Vol. 9, No. 2 (Mar. 1969)
68-60	P. E. Chen & R. E. Lavengood	Stress Fields Around Multiple Inclusions AD 846907	Proc. of Internat. Conf. Structure, Solid Mech. & Eng. Design in Civil Eng. Maters., Part 1, p.75, ed. M. Te'eni, Wiley Interscience, N.Y. 1971.
68-61	* S. W. Tsai	Formulas for the Elastic Properties of Fiber Reinforced Composites AD 834851	
68-62	Void		

68-63	P. E. Chen & T. B. Lewis	Stress Analysis of Ribbon Reinforced Composites AD 846680	Polymer Engr. & Sci., 10, 43 (1970)
68-64	*H. D. Droste & A. T. DiBenedetto	The Glass Transition Temperature of Filled Polymers and its Effect on Their Physical Properties AD 837462	J. Appl. Polymer Science, 13, pp. 2149-2168 (1969)
68-65	O. des. Deex & R. G. Schierding	Silicon Carbide Whisker Reinforced Aluminum Composites AD 836801	J. Comp. Mater., 3, 618 (1969)
68-66	*R. E. Lavengood & L. B. Gulbranson	The Effect of Aspect Ratio on the Fatigue Life of Short Boron Fiber Reinforced Composites AD 848751	Polymer Engr. & Sci., 9, 365 (1969)
68-67	*A. E. Moehlenpah, O. Ishai, A. T. DiBenedetto	The Effect of Time and Temperature on the Mechanical Behavior of "Plasticized" Epoxy Resin Under Different Loading Modes AD 840568	J. Appl. Polymer Sci., 13, 1231 (June 1969)
68-68	*E. M. Wu	Crack Growth in Unidirectional Composites Under Repeated Loadings AD 843586	
68-69	*R. L. Thomas & E. M. Wu	Off-Axis Test of a Composite	J. Composite Materials, Vol. 2, No. 4, 523 (Oct. 1968)
68-70	*P. E. Chen & J. M. Lin	Transverse Properties of Fibrous Composites AD 840592	ASTM Materials Res. & Stds., Vol. 9, No. 8(Aug. 1969)

68-71	* R. C. Reuter, Jr. & S. W. Tsai	Some Observations on the Dynamic Behavior of Composites AD 841838	
68-72	P. E. Chen & L. E. Nielsen	Mechanical Properties of Tape Composites AD 843077	Kolloid Zeitschrift and Zeitschrift fur Polymere, 235, 1, 1174-1181 (1969)
68-73	M. Takano	Rheology of Rod-Like Particles in Viscous Media Part I. Formation of Composites from Single Fibers AD 849285	
68-74	* O. Ishai & R. E. Lavengood	Tensile Characteristics of Discontinuous Unidirectional Glass Epoxy Composites AD 848752	Proceedings SPI Conference, 1969
68-75	Void		
68-76	* E. M. Wu & R. L. Thomas	Interfacial Fracture Phenomena	
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68-77	R. E. Lavengood & R. M. Anderson	Matrix Properties Controlling Torsional Fatigue Life of Fiber Reinforced Composites AD 689042	Proceedings SPI Conference, 1969
68-78	R. G. Schierding	The Study of Extrusion as a Method for Fabricating Metal Matrix Composites AD 847651	

68-79	* O. Ishai & R. E. Lavengood	Characterizing Strength of Unidirectional Composites AD 851245	Composite Materials: Testing and Design, ASTM STP 460, pp. 271-281 (1969)
68-80	L. A. Goettler	Flow Molding of Discontinuous Fiber Reinforced Plastics Literature Survey AD 849965	
68-81	W. M. Haynes & T. L. Tolbert	A Rapid Determination of the Graphite Fiber Content of Plastic-Composites AD 865304	J. Composite Materials, 3, 709-712 (1969)
68-82	P. E. Chen	Strength Properties of Discontinuous Fiber Composites AD 855272	Polymer Engr. & Science, Vol. 11, No. 1, Jan. 1971
69-83	* O. Ishai	Yield and Brittle Failure of Unidirectional Composites Under Uniaxial Tension AD 849286	
69-84	L. E. Nielsen	Dynamic Mechanical Properties of Filled Polymers AD 848438	Applied Polymer Symposia, No. 12, pp. 249-265 (1969)
69-85	Void		
69-86	R. G. Schierding & O. deS. Deex	Factors Influencing the Properties of Whisker-Metal Composites AD 702334	J. Composite Materials, 3, 618-629, Oct. 1969

69-87	L. E. Nielsen & T. B. Lewis	Temperature Dependence of Relative Modulus in Filled Polymer Systems AD 850991	J. Polymer Science, A2, 7, 1705 (1969)
69-88	T. B. Lewis & L. E. Nielsen	Dynamic Mechanical Properties of Particulate Filled Composites AD 862118	J. of Applied Polymer Science, Vol. 14 pp. 1449-1471 (1970)
69-89	* J. L. Kardos & W. L. McDonnell	The Fabrication Morphology and Dynamic Mechanical Properties of a Model Composite System Containing in situ Crown Filler AD 861187	J. Macromol. Sci.-Phys., B6 (2), 397 (1972)
69-90	T. B. Lewis	Ribbon Reinforcements in Composite Materials AD 865290	Proceedings of SPI Conference 1970
69-91	L. A. Goettler	Flow Orientation of Short Fibers in Transfer Molding AD 865328	Proceedings of SPI Conference 1970
69-92	* J. Lin, A. T. DiBenedetto, P. E. Chen	Transverse Properties of Unidirectional Aluminum Matrix Fibrous Composites AD 861188	Polymer Engr. & Sci., 11, 344 (1971)
69-93	* J. Y. L. Ho & P. E. Chen (abstract only)	Impact Mechanics Studies of Isotropic Elastic Thick Plates	
69-94	* P. E. Chen & J. Y. L. Ho (abstract only)	On the Responses of a Specially Orthotropic Fiber-Reinforced Composite Plate Under Dynamic Loadings	

69-95	*O. Ishai, A. E. Moehlenpah, A. Preis	Temperature and Time Effects on Yield and Failure of Unidirectional Glass-Epoxy Composites AD 861189	
69-96	R. G. Schierding & T. L. Tolbert	Flow Molding as a Method for Fabricating Metal Matrix Composites AD 866167	
69-97	R. W. Tock & D. E. McMackins	Experimental Studies of the Tensile Properties of Discontinuous Fiber Reinforced Plastics AD 865291	Proceedings of AIChE Meeting 1970
69-98	*E. Stejskal, D. Droste A. T. DiBenedetto	Pulsed Nuclear Magnetic Resonance Measurements on Filled Polymers AD 865292	Jrnl. of Poly. Sci., Part A2 Vol.9 (1971) pp. 187-189
69-99A	*O. Ishai & R. E. Lavengood	The Mechanical Performance of Cross-Plied Fiber Glass-Epoxy Composites AD 869004	Polymer Engr. & Sci., Vol. 11, No. 3, May 1971
69-99		The Mechanical Performance of Bi-directional Fiber-Glass Polymeric Composites	Israel J. of Technology, Vol. 8, No. 1-2, 1970, pp. 101-109
69-100	Void		
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70-105	*A. E. Moehlenpah, O. Ishai, A. T. DiBenedetto	The Effect of Time and Temperature on the Mechanical Behavior of Epoxy Composites. Part I. Tangent Modulus and Stress Relaxation. AD 869548	Polymer Eng. & Science, Vol. 11, No. 2, March 1971
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72-151	L. A. Goettler	Characterization of Fiber Orientation Patterns Produced in the Flow Molding of Reinforced Thermosets	
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74-169	Richard O. Maschmeyer & Christopher T. Hill	Rheology of Concentrated Suspensions of Fibers in Tube Flow: II. An Exploratory Study
74-170	Richard O. Maschmeyer & Christopher T. Hill	Rheology of Concentrated Suspensions of Fibers in Tube Flow: III. Suspensions With the Same Fiber Length Distribution.

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COMPOSITE-RELATED ACTIVITIES

Name	Degree Earned & Date Received	Advisor	Employer After Graduation
David C. Morris	M.S. - Jan. 1966	Gulbransen	Monsanto Company
Jacques Joseph	M.S. - Jan. 1967	Kardos/Nielsen	Industry, Paris, France
Richard Lavengood	M.S. - Jan. 1968	Gulbransen	Monsanto Company
William McDonnell	M.S. - June 1968	Kardos	Oil Shale Company, Australia
Aron Preis	M.S. - June 1968	Isnai	Technion, Israel
Robert Johnson	M.S. - Jan. 1970	Duffey	Aeronautical Company
Stephen Lowy	M.S. - Jan. 1970	Kardos	Monsanto Company
Gopel Gaonkar	D.Sc. - Jan. 1967	Hohenemser	Washington University
Dieter Droste	D.Sc. - Jan. 1969	DiBenedetto	DuPont, Delaware
Samiron Chatterjee	D.Sc. - Jan. 1968	Gulbranson	
Jimmy Ho	D.Sc. - Jan. 1969	DiBenedetto	TRW, Inc., California
Jing Ming Lin	D.Sc. - June 1969	DiBenedetto	Parks Aeronautical College
Ashok Dhingra	D.Sc. - Jan. 1970	Gulbransen	DuPont
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Theodore Neisen	D.Sc. - June 1971	Bagley	Exxon, New Jersey
M. Scigliano	D.Sc. - June 1971	Bagley	Monsanto Company
Adrian Cooper	D.Sc. - June 1972	Wu	Babcock & Wilcox
James V. Gauchel	D.Sc. - June 1972	DiBenedetto	U.S. Navy Res. Lab.
B. S. Mehta	D.Sc. - June 1972	DiBenedetto/Kardos	Mobil Oil Company
Daniel Peretz	D.Sc. - June 1972	DiBenedetto	Technician, Haifa
Ken Yang	D.Sc. - June 1973	Kardos	IBM
Roger Fountain	D.Sc. - June 1973	Kardos	American Standard
S. V. Kao	D.Sc. - Dec. 1973	Nielsen	McGill U. (post doc)
F. Nazem	D.Sc. - June 1973	Hill	U. of Wisconsin (post doc)
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D. J. Stubblefield	M.S. - June 1972	DiBenedetto	Inter. Am. Devel. Bank (Mex.)
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W. Fujimoto	M.S. - June 1972	Noton	McDonnell-Douglas
D. A. Hurwitz	M.S. - June 1972	Roberts	Small Coating Industry (Maine)
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K. D. Roberts	M.S. - June 1973	Hill	U. S. Army
J. Raisoni	D.Sc. - Aug. 1974	Kardos	Ford Motor Company
J. Sandoval	M.S. - Aug. 1974	Kardos	U. of Mexico
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R. Maschmeyer	D.Sc. - June 1974	Hill	Corning Glass Company
B. Whipple	D.Sc. - June 1974	Hill	Whirlpool Corporation
T. A. Duffy	M.S. - June 1974	Kardos/Michno	M & T Chemical
K. Jerina	D.Sc. - June 1974	Kardos	MTS Systems, Inc.
L. Teasley	M.S. - June 1974	Hill	Monsanto Company